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(12)   **EUROPEAN PATENT SPECIFICATION**

(54) **METHOD AND APPARATUS FOR CALIBRATING AN MWD ELECTROMAGNETIC LOGGER**

VERFAHREN UND VORRICHTUNG ZUM KALIBRIEREN EINES ELEKTROMAGNETISCHEN
BOHRLOCHMESSGERÄTS WÄHREND DES BOHRENS

PROCEDE ET APPAREIL D'ETALONNAGE D'UN ENREGISTREUR ELECTROMAGNETIQUE DE
MESURES EN COURS DE SONDAGES (MCS)

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Description

This invention relates to an apparatus and method for calibrating an electromagnetic logging tool such as an induction logger, that is used to measure the conductivity of the surrounding formation while a borehole is being drilled therethrough. The apparatus is particularly useful as a secondary standard for field use in testing MWD loggers.

Electromagnetic (induction) logging tools for measuring the electrical properties of subsurface earth formations are well known. The logging tool may be run into a borehole on a wireline after the hole has been drilled. Alternatively the tool may be incorporated into the lower end of the drill string, near the bit so as to log the formation parameters while the borehole is being drilled (i.e. Measurement While Drilling or MWD). The advantage of the latter method is that the tool can measure formation parameters before the borehole sidewall has become contaminated with the drilling fluids. Furthermore, the desired measurements are gathered in near real time rather than days or weeks later as is the case with wireline logging.

Typical induction tools consist essentially of a transmitter coil and two receiver coils that are mounted concentrically on a mandrel. The two receiver coils may be separated by, perhaps, 30 cm and the transmitter coil may be about 0.7 m from the nearest receiver coil. In some tools, a second transmitter is provided at the opposite end of the receiver array. The respective coils commonly consist of several turns of wire of a suitable size that are insulated from the mandrel. An electronics module is incorporated into the tool to provide power to the transmitter coil and to detect the signals in the receiver coils. Means are furnished to either store the measured formation parameters or to transmit the gathered data to surface equipment, or both.

At timed intervals such as every 100 milliseconds (ms), a 1- or 2-mHz sinusoidal signal at a potential of about 200 volts is launched into the transmitter coil. If two transmitter coils are provided, the transmitters are excited in alternate cycles and the received signals resulting alternate cycles are averaged. The electromagnetic field radiates outwardly from the transmitter, through the formation surrounding the borehole, to each of the receivers in turn. The received signals are very weak, on the order of 1 to 500 μv. The phase difference between the signals received by the respective receivers, as well as the amplitude ratio are parameters that are a function of the formation resistivity which may range from about 0.1 to about 100 ohm-meters or more. Those measurements provide a penetration depth into the sidewall formation of nearly two meters.

An induction logging tool is essentially a precision voltmeter that must be calibrated with respect to a laboratory standard. Usually, the tool is calibrated in a large brine tank where the resistivity of the test medium (salt water) can be accurately controlled. The test results take the form of response curves plotted as formation resistivity vs. phase shift and amplitude ratio. See for example, Figures 1 and 2.

MWD logging tools must be rugged to withstand the drilling stresses. Made of conductive but non-magnetic metal such as beryllium-copper or monel metal, an MWD logging tool may be two or three meters long, 15 cm in diameter and is quite heavy. A secondary standard is used for field calibration of an MWD induction logging tool in the field both before and after a logging run. Of course, there is no reason why a portable secondary standard could not also be used on-site to confirm the calibration of a wireline tool.

The theory of the operation of an inductive logging tool mounted on a conductive mandrel is explained in a paper entitled *The theory of 2 mHz Resistivity Tool and its Application to Measurement-While-Drilling* by D. Coope et al. in *The Log Analyst*, v. 25, No. 3, May-June, 1984. The concepts are well known. Hence it is not considered to be necessary here to expand further upon the theory of operation. An analysis of the response of an MWD tool is presented by Q. Zhou et al. in *MWD Resistivity Tool Response in a Layered Medium*, published in *Geophysics*, v. 56, No. 11, November 1991.

U.S. patent No. 4,876,511, issued 10/24/89 to Brian Clark for a Method and Apparatus for Testing and Calibrating an Electromagnetic Logging Tool, discloses an external testing apparatus for a logging tool which includes at least a transmitting antenna and dual-channel receiving antennas. A shielded receiving device is clamped around the transmitting antenna and intercepts the transmitted signal. A shielded transmitting device is positioned around the receiving antennas of the tool and transmits to the receiving antennas a signal which has a phase and/or amplitude that is related to the signal transmitted by the tool's transmitting antenna in a known manner. It simulates the effect that a geological formation would have on the signal if it were to travel from the tool's transmitting antenna through the formation. Since the simulated effect is known, the output of the tool may be verified as being correct or it may be corrected if it is erroneous.

Another reference is found in US patent No. 5,001,675, issued 03/19/91 to G. H. Woodward for a Phase and Amplitude Calibration System for Electromagnetic Propagation Based on Earth Formation Evaluation Instruments. The inventor teaches an automatic calibration system which compensates for errors caused by temperature and pressure variations in a borehole. In this system, an auxiliary calibration antenna is tightly coupled physically to each of the spaced-apart receiving antennas of a dual-channel logging tool. In-phase equal-amplitude reference signals are applied to the two measurement channels from the calibration antennas to the respective receiving antennas. Each of the calibration antennas communicates with an attenuator which acts to make the calibration antennas transparent to the receiving antenna when the latter are in the meas-

urement mode.

A Russian paper entitled *Calculation of Calibration Loops for Induction Logging Tools*, by V. N. Boganik et al., published in *News From Colleges*, 1965, No. 9, describes a single closed calibration loop that may be used with a wireline tool.

The first reference discloses a rather awkward calibration assembly that must be clamped around the logging tool mandrel. In addition, a good deal of complex circuitry is required to match the calibration antennas to the receiving and transmitting antennas that are mounted on the tool itself. The second reference is merely a relative compensation device to equalize the parameter measurements from different depths to a common base line. The device of the '675 patent is not an absolute-value calibration tool. The Russian device is a single closed loop suitable for use with a wireline logger but not with MWD equipment.

There is a need for a simple, portable secondary calibration standard that first can be exercised in the laboratory and later used for field testing of a logging tool. It is desirable that the calibration device should be passive and not dependent for its operation upon auxiliary circuitry which, itself, would require calibration.

A calibration device is provided for a down-hole electromagnetic logging tool, the tool including a conductive mandrel for concentrically supporting at least a transmitter and a pair of spaced-apart receivers. The calibration device includes multiple concentric co-planar conducting loops mounted concentric with the two spaced-apart receivers. Each conductive loop includes a multiple-tap series resistor for simulating the effect of formations having different known resistivities on the ratio of the signal amplitudes as seen by the two receivers when the conductive loops are excited by an electromagnetic field radiated by the transmitter.

In another aspect of this invention, each conductive loop includes in addition, a series capacitor for simulating the effect of formations characterized by different known resistivities, on the phase difference between the signals as seen by the two receivers when excited by an electromagnetic field radiated by the transmitter.

A method for calibrating an electromagnetic logging instrument that includes a conductive mandrel upon which are concentrically mounted a transmitter and two spaced-apart receivers remote from the transmitter. The method includes the steps of mounting a plurality of co-planar conductive loops concentric with the receivers. Inserting a multiple-tap series resistor in each of the plurality of conductive loops. Radiating an electromagnetic field from the transmitter. Intercepting a portion of the radiated electromagnetic field by the plurality of conductive loops and re-radiating the intercepted field portion into the receivers. Adjusting the resistance of the tapped series resistors in known discrete steps to simulate the effect of formations having different known resistivities. Measuring the amplitude ratios of the signals seen by the two receivers as a function of the known formation

resistivity corresponding to each discrete resistance step.

The method further includes the additional step of inserting a capacitor in series with the tapped series resistors and adjusting the resistance thereof in known discrete steps to simulate the effect of different formations having known resistivities. Measuring the phase shift between the signals, as seen by the two receivers, as a function of the known formation resistivity corresponding to each discrete resistance step.

A method for calibrating an electromagnetic logging tool that includes at least one transmitter and a pair of receivers, all concentrically mounted in spaced-apart configuration on a mandrel. The calibration is accomplished by propagating an electromagnetic field from the transmitter. An electromagnetic radiator is interposed between the transmitter and the receivers. When the electromagnetic radiator is excited by the electromagnetic field radiated by the transmitter, the radiator electrically irradiates the pair of receivers at selected discrete intensity levels that simulate the effect of formations having different known resistivities.

In response to the irradiation, in one embodiment, the two receivers generate output signals having an amplitude ratio that is a function of the simulated formation resistivity.

In a second embodiment, the two receivers generate output signals whose phase difference is a function of the simulated formation resistivity.

The novel features which are believed to be characteristic of the invention, both as to organization and methods of operation, together with the objects and advantages thereof, will be better understood from the following detailed description and the drawings wherein the invention is illustrated by way of example for the purpose of illustration and description only and are not intended as a definition of the limits of the invention:

> FIGURE 1 shows the response curve for the measured signal phase angle difference between two receivers as a function of formation resistivity;
> FIGURE 2 is the response curve that relates the measured signal amplitude ratio to formation resistivity;
> FIGURE 3 illustrates schematically the method of mounting the calibration device on an MWD mandrel;
> FIGURE 4a is a plan view of one form of the calibration fixture showing multiple calibration loops and a plug-in external impedance module for terminating the calibration loops;
> FIGURE 4b is a cross section along line 4b-4b of FIGURE 4a;
> FIGURE 4c is a schematic diagram of an external impedance circuit for terminating the calibration loops;
> FIGURE 5 exhibits the dynamic ranges of the signal amplitude ratio as seen by one loop vs. multiple

loops as a function of the value of a quantizing resistor; and

FIGURE 6 compares the dynamic range of the phase angle difference as seen by one loop vs. multiple loops as a function of the value of a quantizing resistor in the presence of a series capacitor.

Figure 3 is a schematic drawing of an induction logger assembly generally shown as 10. The assembly consists of a mandrel 12, which, in the case of an MWD tool is conductive but non-magnetic. Transmitter wire-coils T1 and T2 are wrapped coaxially on the mandrel in grooves (not shown) cut around the outer surface of the mandrel. The two coils may be about 1.7 meters (m) apart. Receiver wire-coils R1 and R2 are coaxially wrapped in grooves betwixt the transmitter coils as shown, separated by about 0.3 m. The respective transmitter and receiver coils are insulated from the conductive mandrel. Suitable electronics modules (not shown) are incorporated inside the logging tool.

In operation, the transmitter wire-coils act as transmitting antennas for an electromagnetic field and the receiver coils serve as receiving antennas. For brevity, we shall refer to those items as transmitters or receivers respectively. For calibration purposes, a calibration fixture 14 is positioned around the mandrel, preferably between the receivers but not necessarily limited to that location. The calibration fixture consists of a plurality of closed conductive loops that are co-planar and concentrically mounted around the mandrel coaxially with the transmitters and receivers.

Although the theory of operation of the induction tool is known, it will be briefly reviewed here with respect to a single calibration loop. When a transmitter is excited in the absence of a calibration loop, a voltage V_p is induced in the receivers. If we add a closed conductive loop, a voltage V_l is induced in the loop which re-radiates a voltage contribution V_s to the receivers. Then the total voltage, V_t induced in the receivers with a calibration loop present, is

$$Vt = V_p + V_{s.} \qquad (1)$$

V_s can be calculated from the voltage V_l and current I_l induced in the calibration loop. The quantity V_l can be calculated by the method of Coope et al. cited earlier. The induced current in the calibration loop is given by

$$I_l = V_l / Z_l \qquad (2)$$

where the loop impedance Z_l is

$$Z_l = R_l + i2\pi f L_{l.} \qquad (3)$$

The internal resistance R_l and self-inductance L_l of the loop can be calculated or measured, f is the operating frequency and i is the quadrature operator. From (2), the voltage V_s induced in the receiver can be quantified.

From equation (3) it will be seen that the voltage induced in the receivers is a function of the resistance of the calibration loop. By introducing an external variable or quantizing resistor, R, having multiple taps to provide discrete resistance steps, in series with the internal resistance R_l of the calibration loop, corresponding discrete voltage levels will be induced into each of the receiver coils. The ratio of the discrete induced voltage (amplitude) levels can be correlated with formation resistivities based upon laboratory measurements on the calibration fixture in a test tank as earlier explained. The variable resistor in combination with the conductive calibration loop thus simulates the effect of formations having different known resistivities.

I have found that, for amplitude-ratio measurements, a single calibration coil, while useful, does not provide a dynamic range sufficiently broad to simulate the effect of formations that have a wide variation in resistivity. Accordingly, I provide a multiple-loop configuration as will be described later in connection with Figures 4a and 4b. When a multiple-loop configuration is used, the mutual inductance between the loops must be considered.

I have also found that to increase the dynamic range of phase-angle-difference measurements, it is preferable that the calibration loop impedance Z_l should be nearly pure resistance. To that end, for phase-angle-difference measurements, an optional capacitor having capacitance C, is coupled in series with the variable resistor R so that the external impedance Z_e becomes

$$Z_e = R + [1/i2\pi fC]. \qquad (4)$$

Figures 4a and 4b illustrate a multiple-loop calibration fixture 14. The fixture consists of a flat disk-like support 16 of some insulating material such as epoxy or other plastic. It has a radius of about 0.5 m and may be one or two centimeters thick. A collar 18 of suitable material fits in the center of disk 16. The inner diameter of the collar is sufficient to slide over the outer diameter of mandrel 12 (Figure 3). The fixture is locked in place on the mandrel by means of one or more set screws such as 20. Two conductive calibration loops 22 and 24 are fastened to disk 16 by any convenient means. Two loops are shown by way of example but not by way of limitation since up to five or more loops may be used and indeed, are preferred. Each loop is terminated by female plugs such as 26 and 28, 30 and 32, for receiving the prongs of external impedance module such as 34 in series with a loop. Module 34 includes a resistor R and capacitor C. A module is provided for each loop. Several modules, each having a different-valued fixed resistor may be

used for calibration purposes or a single module having a tapped variable resistor could be used such as shown in Figure 4c. The version in Figure 4c forms a multiple-tap impedance quantizing means for the calibration loop that it terminates. For phase-angle difference measurements, separate modules may be furnished either with or without capacitors or means such as 35, Figure 4c, can be supplied to switch the capacitor out of the circuit as desired.

The two exemplary loops shown in Figures 4a and 4b have radii of 0.5 and 0.44 meter respectively. Their self-inductances are 4.7 and 4.4 µH and the mutual inductance is 1.24 µH. The wire resistances of the loops are 0.52 and 0.46 ohm. The capacitance, if used, is 5.6 nF. The quantities listed are exemplary only; they should not be considered to be limiting.

From the above discussion, it is seen that the calibration fixture 14 is completely passive in operation. It is simple' in construction and is readily portable for use in the field. In effect, the calibration fixture serves as an electromagnetic radiator that is interposed between a transmitter and the receivers. When the radiator is excited by the electromagnetic field propagating from the transmitter, the radiator irradiates the receivers at selected discrete intensity levels to simulate the effect of formations having different known resistivities.

Figure 5 is a graph that shows the amplitude ratio, in dB, between the output signals from the two receivers as a function of the value of the external quantizing resistor (without a series capacitor) for a single calibration loop, curve 36, and for a set of five calibration loops, curve 38. The substantial improvement in dynamic range using multiple loops is quite apparent.

Figure 6 is a graph of the phase-angle difference, in degrees, between the output signals of the two receivers as a function of the value of the external quantizing resistor with the series capacitor, for a single loop, curve 40 and for multiple calibration loops, curve 42. Curves 44 and 46 show the responses for single and multiple loops respectively without a series capacitor. Without the series capacitor, the calibration tool is virtually useless for phase-angle difference measurements. The multiple-loop configuration, with capacitors, provides a definite improvement in dynamic range.

For a calibration operation, the induction logging tool is laid across supports or is air-hung from a sky hook. The calibration fixture 14, whose calibration accuracy had been previously verified in the laboratory, is removably positioned over mandrel 12 and locked in place at a desired location therealong with set screw 20. It is assumed of course that the internal electronics module associated with the logging tool is provided with externally-accessible test-probe jacks. The transmitter(s) is excited to radiate an electromagnetic field. The eddy currents induced in the calibration loops re-radiate a contribution signal to the receivers provided that one or more loops are terminated by corresponding external impedance modules such as 34. An unterminated loop

is ineffective.

During a first test cycle, the quantizing resistors associated with each loop are adjusted in discrete steps and the observed amplitude ratio between the receiver output signals is noted for each discrete calibration step. The difference between the observed amplitude-ratio values and the true amplitude-ratio values is recorded in a correction table. The true amplitude-ratio value corresponding to each discrete resistor step as picked from a calibrated graph such as that of Figure 5. A second calibration cycle may then be run for producing a phase-angle difference correction table. Alternatively, if such a capability is included in the internal electronics module of the tool, the error corrections can be introduced instrumentally by tweaking the calibration circuitry.

This invention has been described with a certain amount of particularity for exemplary purposes only. Those skilled in the art will conceive of variations in the method and equipment but which will nevertheless fall within the scope of the disclosure which is limited only by the appended claims.

Claims

1. A calibration device for use with an electromagnetic logging tool, the logging tool including an elongated mandrel (12), having a longitudinal axis, coaxially supporting at least one transmitter (T1, T2) and two spaced-apart receivers (R1, R2) mounted remotely from the transmitter, the device(16) comprising means (22, 24) for receiving radiation from the transmitter (T1) and for radiating the received radiation to the receivers (R1, R2), characterised in that the device is a passive device which comprises:

    an insulating support means (16) removably securable around said mandrel between said transmitter and said receivers;
    a plurality of concentric coplanar conductive calibration loops (22, 24) mounted on said support means · for receiving radiation from said transmitter and for re-radiating the received radiation to said receivers whilst said calibration loops are mounted coaxially with respect to said transmitter and said receivers; and impedance quantizing means (34) for terminating each one of said conductive calibration loops (22, 24) in discrete impedance steps such that the radiation re-radiated to said receivers (R1, R2) is attenuated by said quantizing means (34) to simulate, when said tool is under calibration, the signal attenuation effects of earth formations having different resistivities.

2. A device as defined by claim 1, wherein the quantifying means comprises a multiple-tap impedance means (34).

3. A device as defined by claim 2, wherein each said impedance quantizing means (34) comprises a variable series resistance (R).

4. A device as defined by claim 1, 2 or 3, wherein each said impedance quantizing means (34) includes a fixed series capacitor (C).

5. A device as defined by claim 1, 2, 3 or 4, and comprising an aperture (18) in said support means (16) within which said mandrel can be located to maintain the loops coaxial with the receivers (R1, R2).

6. A device as defined by any one of the preceding claims, in combination with said logging tool, the loops being mounted coaxially with the receivers.

7. A device as defined by claim 6, wherein the logging tool is air-hung.

8. A device as defined by claim 6 or 7, wherein said calibration loops (22, 24) are located midway between said receivers (R1, R2).

9. A device as defined by claim 6, 7 or 8, wherein said mandrel (12) is electrically conductive.

10. A method for calibrating an electromagnetic logging tool prior to its deployment for use in measurement-while-drilling operations, said tool including at least one transmitter (T1) and a pair of receivers (R1, R2) all of which are concentrically mounted in spaced-apart configuration on a conductive mandrel (12), the method comprising interposing an electromagnetic radiator (22, 24) between said transmitter (T1) and said receivers (R1, R2) and exciting said electromagnetic radiator by an electromagnetic field radiated from said transmitter, the method being characterised by varying, in discrete steps, the impedance value of said electromagnetic radiator so that it irradiates said receivers at selected discrete intensity levels, the discrete intensity levels simulating the signal-attenuation effects of electromagnetic signals propagating through earth formations having different known resistivities thereby to quantify receiver output signals as a function of said known resistivities.

11. A method as defined by claim 10 comprising:

measuring the amplitude ratios of the output signals from said receivers as a function of said discrete impedance values;
providing a calibration table of formation resistivity vs. true amplitude ratio as a function of the discrete impedance values; and
comparing the measured amplitude ratios with the true amplitude ratios corresponding to each

selected discrete impedance value to determine a correction factor to be applied to the measured receiver output-signal amplitude ratios.

12. A method as defined by claim 10 or 11, comprising:

measuring the phase-angle differences of the output signals from said receivers as a function of said discrete impedance value;
providing a calibration table of formation resistivity vs. true phase-angle difference corresponding to each selected discrete impedance value to determine a correction factor to be applied to the measured receiver output-signal phase-shift differences.

13. A method as defined by claim 10, 11 or 12, comprising:

mounting a plurality of co-planar conductive calibration loops (22, 24), as said electromagnetic radiator, around said mandrel (12) concentrically with the transmitter (T1) and receivers (R1, R2);
closing each said calibration loop with a series impedance;
radiating an electromagnetic field from said transmitter;
changing the series impedance value in discrete steps for attenuating the level of the electromagnetic field that is re-radiated into said receivers to simulate the signal-attenuation effects of earth formations having different known resistivities.

14. A method as defined by claim 13, wherein the changeable impedance is provided by a series resistance.

15. A method as defined by claim 14, wherein the resistance is a multiple-tap resistance.

Patentansprüche

1. Kalibriervorrichtung zum Gebrauch in einer elektromagnetischen Aufzeichnungsvorrichtung, wobei die Aufzeichnungsvorrichtung einen länglichen Dorn (12) umfaßt, der eine Längsachse hat und koaxial zumindest einen Sender (T1, T2) trägt und zwei beabstandete Empfänger (R1, R2), die entfernt vom Sender montiert sind, und die Vorrichtung (16) Mittel (22, 24) zum Empfangen von Strahlung aus dem Sender (T1) enthält und zum Abstrahlen der empfangenen Strahlung zu den Empfängern (Rl, R2), dadurch gekennzeichnet, daß die Vorrichtung eine passive Vorrichtung ist, die umfaßt:

eine isolierende Halteeinrichtung (16), die lösbar um den Dorn herum zwischen dem Sender und den Empfängern befestigt werden kann;
eine Anzahl konzentrischer koplanarer Kalibrierschleifen (22, 24), die auf den Halteeinrichtungen montiert sind, um Strahlung aus dem Sender zu empfangen und die empfangene Strahlung wieder an die Empfänger abzustrahlen, wobei die Kalibrierschleifen bezüglich des Senders und der Empfänger koaxial montiert sind; und
eine Impedanzquantisiervorrichtung (34) zum Abschließen einer jeden leitfähigen Kalibrierschleife (22, 24) in diskreten Impedanzschritten, so daß die Quantisiervorrichtung (34) die zu den Empfängern (R1, R2) abgestrahlte Strahlung dämpft, um beim Kalibrieren der Vorrichtung die Signaldämpfungswirkungen der Erdformationen zu simulieren, die unterschiedliche Widerstände aufweisen.

2. Vorrichtung nach Anspruch 1, wobei die Quantisiervorrichtung eine Impedanzvorrichtung (34) mit mehrfachen Abgriffen enthält.

3. Vorrichtung nach Anspruch 2, wobei jede Impedanzquantisiervorrichtung (34) einen veränderbaren Reihenwiderstand (R) enthält.

4. Vorrichtung nach Anspruch 1, 2 oder 3, wobei jede Impedanzquantisiervorrichtung (34) einen festen Reihenkondensator (C) enthält.

5. Vorrichtung nach Anspruch 1, 2, 3 oder 4, zudem umfassend eine Öffnung (18) in der Halteeinrichtung (16), in der der Dorn angeordnet werden kann, um die Schleifen koaxial zu den Empfängern (R1, R2) zu halten.

6. Vorrichtung nach irgendeinem der vorhergehenden Ansprüche in Verbindung mit der Aufzeichnungsvorrichtung, wobei die Schleifen koaxial zu den Empfängern montiert sind.

7. Vorrichtung nach Anspruch 6, wobei die sich die Aufzeichnungsvorrichtung in Luft befindet.

8. Vorrichtung nach Anspruch 6 oder 7, in der die Kalibrierschleifen (22, 24) in der Mitte zwischen den Empfängern (R1, R2) angeordnet sind.

9. Vorrichtung nach Anspruch 6, 7 oder 8, wobei der Dorn (12) elektrisch leitfähig ist.

10. Verfahren zum Kalibrieren einer elektromagnetischen Aufzeichnungsvorrichtung, bevor sie zum Messen bei laufenden Bohrvorgängen eingesetzt wird, wobei die Vorrichtung zumindest einen Sen-

der (T1) und ein Paar Empfänger (R1, R2) enthält, die allesamt konzentrisch und mit Abstand zueinander auf einem leitfähigen Dorn (12) montiert sind, und das Verfahren das Einfügen eines elektromagnetischen Strahlers (22, 24) zwischen den Sender (T1) und die Empfänger (R1, R2) umfaßt, und das Erregen des elektromagnetischen Strahlers mit einem elektromagnetischen Feld, das der Sender abstrahlt, und das Verfahren dadurch gekennzeichnet ist, daß in einzelnen Schritten der Impedanzwert des elektromagnetischen Strahlers so verändert wird, daß er die Empfänger mit ausgewählten diskreten Intensitätspegeln anstrahlt und die diskreten Intensitätspegel die Signaldämpfungswirkungen der elektromagnetischen Signale simulieren, die sich durch Bodenformationen mit unterschiedlichen bekannten Widerständen ausbreiten, um damit Empfängerausgangssignale in Abhängigkeit von den bekannten Widerständen zu quantifizieren.

11. Verfahren nach Anspruch 10, umfassend:

das Messen der Amplitudenverhältnisse der Empfängerausgangssignale in Abhängigkeit von den diskreten Impedanzwerten;
das Bereitstellen einer Kalibriertabelle der Formationswiderstände abhängig von dem tatsächlichen Amplitudenverhältnis als Funktion der diskreten Impedanzwerte; und
das Vergleichen der gemessenen Amplitudenverhältnisse mit den tatsächlichen Amplitudenverhältnissen entsprechend jedem gewählten diskreten Impedanzwert, um einen Korrekturfaktor zu bestimmen, der auf die gemessenen Empfängerausgangssignal-Amplitudenverhältnisse anzuwenden ist.

12. Verfahren nach Anspruch 10 oder 11, umfassend:

das Messen der Phasenwinkeldifferenzen der Empfängerausgangssignale in Abhängigkeit von den diskreten Impedanzwerten;
das Bereitstellen einer Kalibriertabelle der Formationswiderstände abhängig von der tatsächlichen Phasenwinkeldifferenz entsprechend jedem gewählten diskreten Impedanzwert, um einen Korrekturfaktor zu bestimmen, der auf die gemessenen Empfängerausgangssignal-Phasenverschiebungsdifferenzen anzuwenden ist.

13. Verfahren nach Anspruch 10, 11 oder 12, umfassend:

das Anbringen einer Anzahl koplanarer leitfähiger Kalibrierschleifen (22, 24) als elektromagnetischer Strahler um den Dorn (12) herum konzentrisch zum Sender (T1) und zu den

Empfängern (R1, R2);
das Abschließen jeder Kalibrierschleife mit einer Reihenimpedanz;
das Abstrahlen eines elektromagnetischen Felds aus dem Sender;
das Verändern des Reihenimpedanzwerts in diskreten Schritten zum Dämpfen des Pegels des elektromagnetischen Felds, das wieder in die Empfänger abgestrahlt wird, um die Signaldämpfungswirkungen von Erdformationen zu simulieren, die unterschiedliche bekannte Widerstände haben.

14. Verfahren nach Anspruch 13, wobei die veränderliche Impedanz durch einen Reihenwiderstand bereitgestellt wird.

15. Verfahren nach Anspruch 14, wobei der Widerstand ein mehrfach angezapfter Widerstand ist.

Revendications

1. Dispositif d'étalonnage destiné à être utilisé avec un instrument d'enregistrement électromagnétique, l'instrument d'enregistrement comprenant un mandrin allongé (12), présentant un axe longitudinal, supportant de façon coaxiale au moins un émetteur (T1, T2) et deux récepteurs espacés l'un de l'autre (R1, R2) montés à distance de l'émetteur, le dispositif (16) comprenant un moyen (22, 24) destiné à recevoir un rayonnement provenant de l'émetteur (T1) est destiné à émettre le rayonnement reçu vers les récepteurs (R1, R2), caractérisé en ce que le dispositif est un dispositif passif qui comprend :

    un moyen de support isolant (16) pouvant être fixé de façon amovible autour dudit mandrin entre ledit émetteur et lesdits récepteurs,
une pluralité de boucles d'étalonnage conductrices coplanaires concentriques (22, 24) montées sur ledit moyen de support afin de recevoir un rayonnement provenant dudit émetteur et de réémettre le rayonnement reçu vers lesdits récepteurs alors que lesdites boucles d'étalonnage sont montées de façon coaxiale par rapport audit émetteur et auxdits récepteurs, et
un moyen de quantification d'impédance (34) destiné à compléter chacune desdites boucles d'étalonnage conductrices (22, 24) par pas discrets d'impédance de sorte que le rayonnement réémis vers lesdits récepteurs (R1, R2) soit atténué par ledit moyen de quantification (34) afin de simuler, lorsque ledit instrument est en cours d'étalonnage, les effets d'atténuation du signal des formations géologiques présentant des résistivités différentes.

2. Dispositif selon la revendication 1, dans lequel le moyen de quantification comprend un moyen d'impédance à prises multiples (34).

3. Dispositif selon la revendication 2, dans lequel chaque dit moyen de quantification d'impédance (34) comprend une résistance série variable (R).

4. Dispositif selon la revendication 1, 2 ou 3, dans lequel chaque dit moyen de quantification d'impédance (34) comprend un condensateur série fixe (C).

5. Dispositif selon la revendication 1, 2, 3 ou 4, et comprenant une ouverture (18) dans ledit moyen de support (16), à l'intérieur de laquelle ledit mandrin peut être positionné pour maintenir les boucles coaxiales avec les récepteurs (R1, R2).

6. Dispositif selon l'une quelconque des revendications précédentes, en combinaison avec ledit instrument d'enregistrement, les boucles étant montées de façon coaxiale avec les récepteurs.

7. Dispositif selon la revendication 6, dans lequel l'instrument d'enregistrement est suspendu en l'air.

8. Dispositif selon la revendication 6 ou 7, dans lequel lesdites boucles d'étalonnage (22, 24) sont placées à mi-chemin entre lesdits récepteurs (R1, R2).

9. Dispositif selon la revendication 6, 7 ou 8, dans lequel ledit mandrin (12) est électriquement conducteur.

10. Procédé d'étalonnage d'un instrument d'enregistrement électromagnétique avant sa mise en place pour une utilisation dans des opérations de mesures au cours de sondage, ledit instrument comprenant au moins un émetteur (T1) et une paire de récepteurs (R1, R2), dont la totalité est montée de façon concentrique suivant une configuration espacée sur un mandrin conducteur (12), le procédé comprenant l'interposition d'un radiateur électromagnétique (22, 24) entre ledit émetteur (T1) et lesdits récepteurs (R1, R2) et l'excitation dudit radiateur électromagnétique par un champ électromagnétique qui rayonne à partir dudit émetteur, le procédé étant caractérisé en ce que l'on fait varier, par pas discrets, la valeur d'impédance dudit radiateur électromagnétique de sorte qu'il illumine lesdits récepteurs à des niveaux d'intensité discrets sélectionnés, les niveaux d'intensité discrets simulant les effets d'atténuation du signal des signaux électromagnétiques se propageant au travers des formations géologiques présentant des résistivités connues différentes afin de quantifier ainsi les signaux de sortie du récepteur en fonction desdites résistivités connues.

11. Procédé selon la revendication 10, comprenant :

    la mesure des rapports des amplitudes des si-
    gnaux de sortie provenant desdits récepteurs
    en fonction desdites valeurs d'impédance dis-
    crètes,
    la fourniture d'une table d'étalonnage de la ré-
    sistivité de la formation suivant le rapport des
    amplitudes réelles en fonction des valeurs d'im-
    pédance discrètes, et
    la comparaison des rapports des amplitudes
    mesurées avec les rapports des amplitudes
    réelles correspondant à chaque valeur d'impé-
    dance discrète sélectionnée afin de déterminer
    un facteur de correction à appliquer aux rap-
    ports des amplitudes des signaux de sortie me-
    surés des récepteurs.

12. Procédé selon la revendication 10 ou 11,
    comprenant :

    la mesure des différences réelles d'angle de
    phase des signaux de sortie provenant desdits
    récepteurs en fonction de ladite valeur d'impé-
    dance discrète,
    la fourniture d'une table d'étalonnage de résis-
    tivité de la formation suivant les différences
    d'angle de phase réelles correspondant à cha-
    que valeur d'impédance discrète sélectionnée
    afin de déterminer un facteur de correction à
    appliquer aux différences des déphasages me-
    surées des signaux de sortie des récepteurs.

13. Procédé selon la revendication 10, 11 ou 12,
    comprenant :

    le montage d'une pluralité de boucles d'étalon-
    nage conductrices coplanaires (22, 24), en tant
    que dit radiateur électromagnétique, autour du-
    dit mandrin (12) de façon concentrique avec
    l'émetteur (T1) et les récepteurs (R1, R2),
    la fermeture de chaque dite boucle d'étalonna-
    ge avec une impédance série,
    le rayonnement d'un champ électromagnétique
    à partir dudit émetteur,
    la modification de la valeur de l'impédance sé-
    rie par pas discrets afin d'atténuer le niveau du
    champ électromagnétique qui est à nouveau
    rayonné jusque dans lesdits récepteurs en vue
    de simuler les effets d'atténuation de signal des
    formations géologiques présentant des résisti-
    vités connues différentes.

14. Procédé selon la revendication 13, dans lequel l'im-
    pédance modifiable est procurée par une résistan-
    ce série.

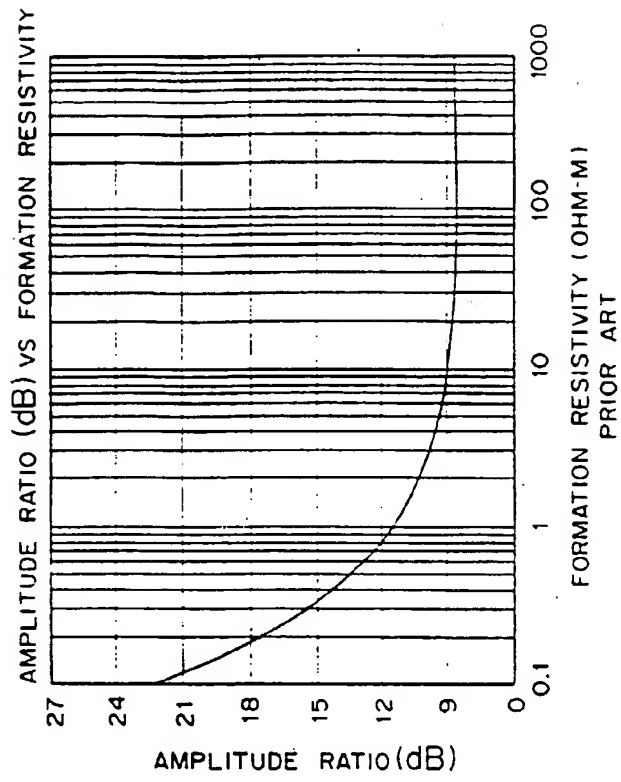15. Procédé selon la revendication 14, dans lequel la
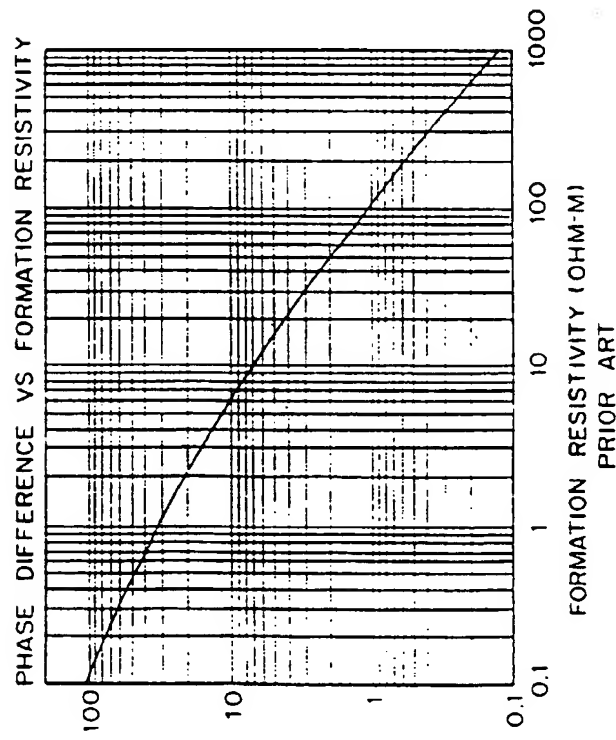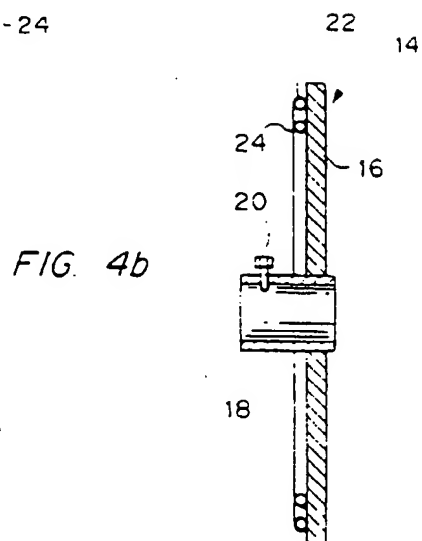
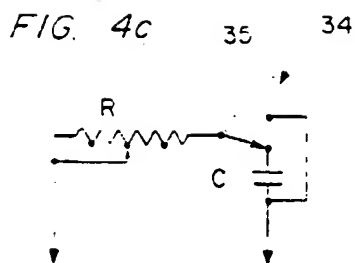résistance est une résistance à prises multiples.

AMPLITUDE RATIO (dB) VS FORMATION RESISTIVITY

FORMATION RESISTIVITY (OHM-M)
PRIOR ART

AMPLITUDE RATIO (dB)

FIG. 2

PHASE DIFFERENCE VS FORMATION RESISTIVITY
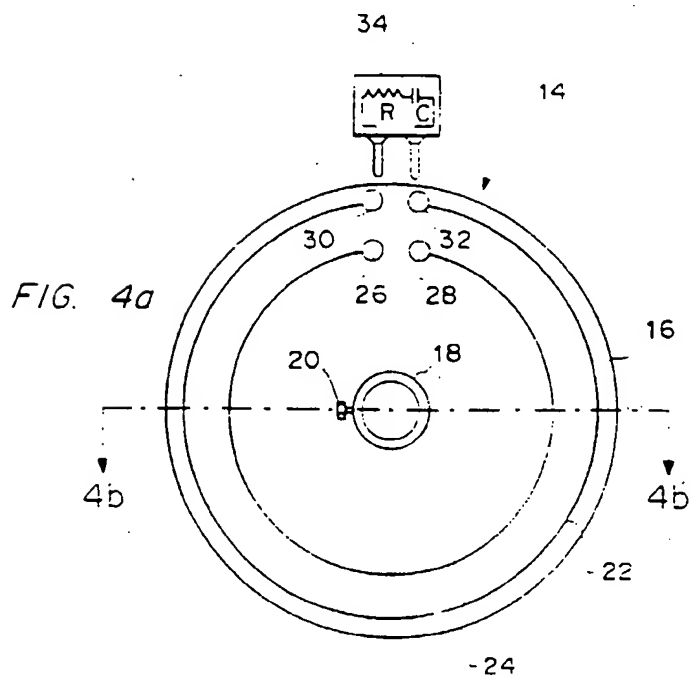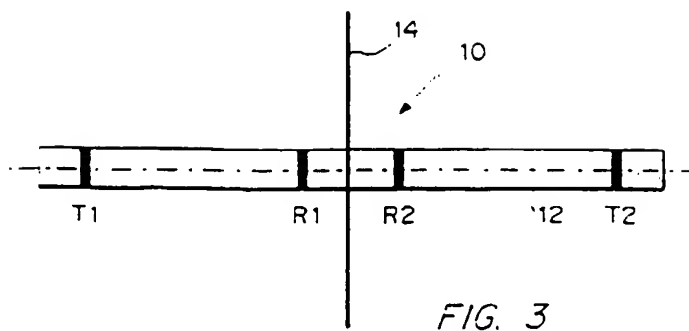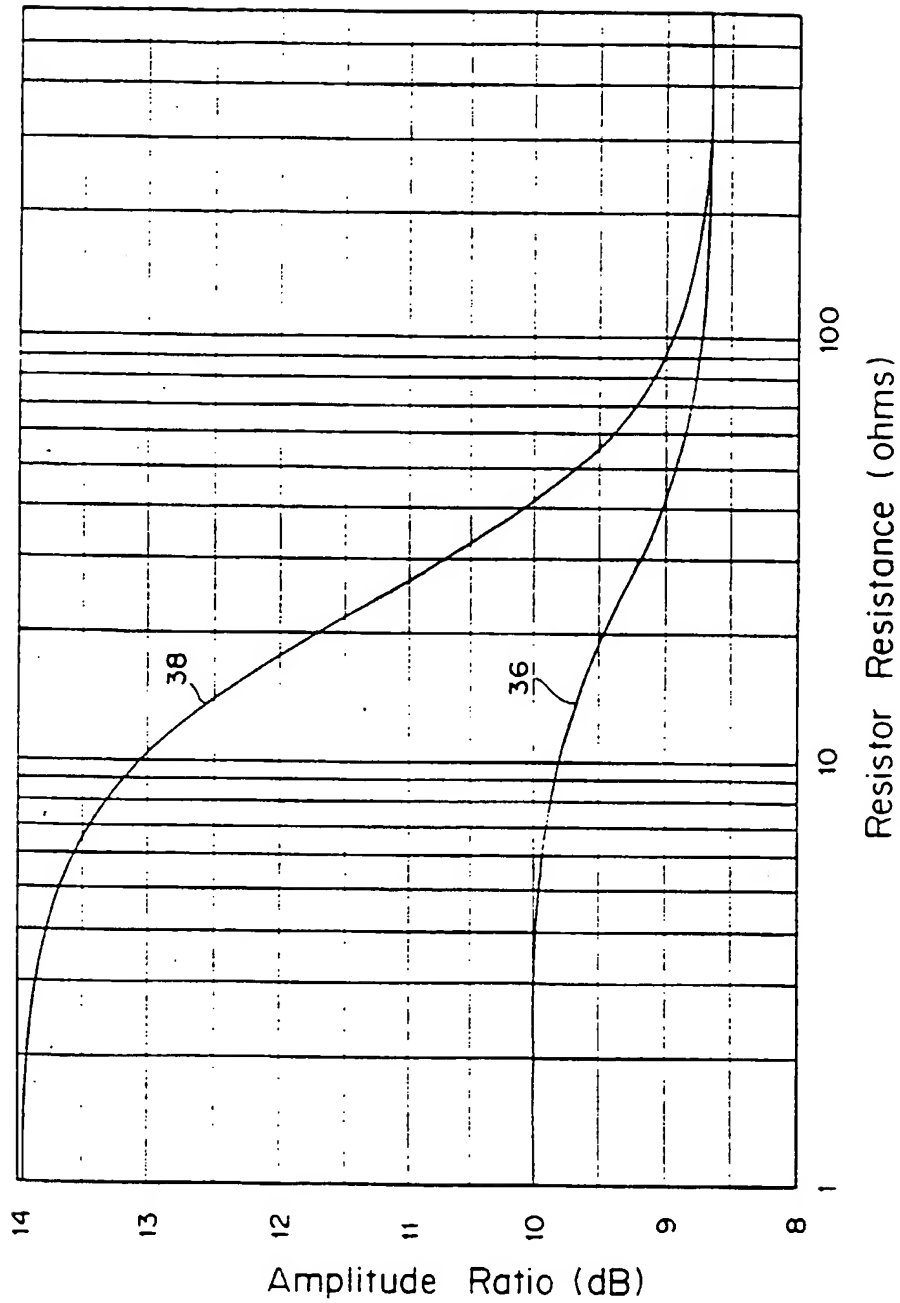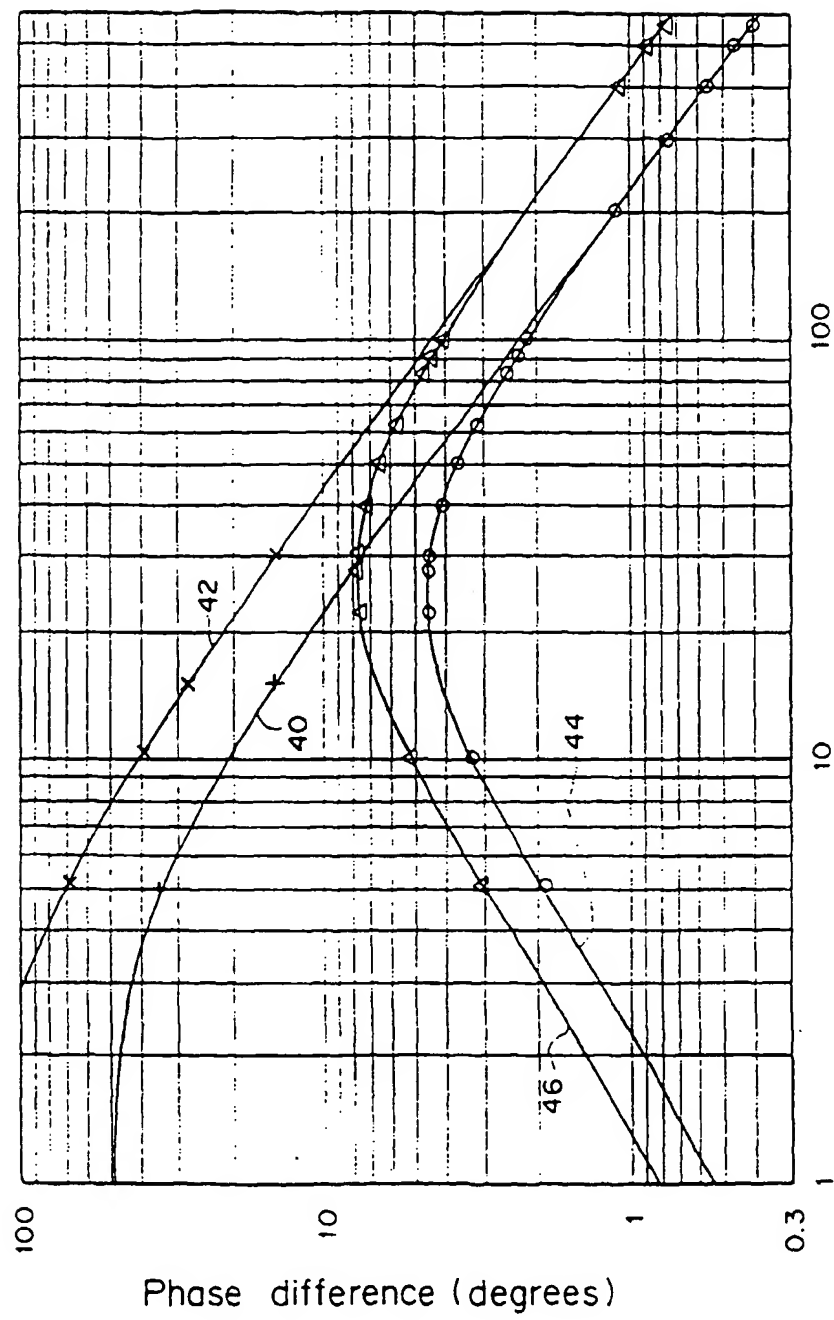
FORMATION RESISTIVITY (OHM-M)
PRIOR ART

FIG. 1

10

FIG. 3

FIG. 4a

FIG. 4c

FIG. 4b

FIG. 5

Resistor Resistance (ohms)

Amplitude Ratio (dB)

FIG. 6